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HIGH CURRENT ION SOURCE DEVELOPMENT FOR HEAVY ION FUSION*

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We are developing high-current-density high-brightness sources for Heavy Ion Fusion applications. Heavy ion driven inertial fusion requires beams of high brightness in order to achieve high power density at the target for high target gain. At present, there are no existing ion source types that can readily meet all the driver HIF requirements, though sources exist which are adequate for present experiments and which with further development may achieve driver requirements. Our two major efforts have been on alumino-silicate sources and RF plasma sources. Experiments being performed on a 10-cm alumino-silicate source are described. To obtain a compact system for a HIF driver we are studying RF plasma sources where low current beamlets are combined to produce a high current beam. A 80-kV 20- μ s source has produced up to 5 mA of Ar^+ in a single beamlet. The extraction current density was 100 mA/cm². We present measurements of the extracted current density as a function of RF power and gas pressure, current density uniformity, emittance, and energy dispersion (due to charge exchange).

I. ALUMINO-SILICATE SOURCES

The “standard” induction linac’s approach to HIF will use high current ion beams that have >0.5 ampere per channel from their ion sources. An HIF driver system may have an array of a hundred ion beams with a final beam energy in the multi-GeV range. A general description of the ion source and injector requirements along with various options can be found in previous papers.^{1, 2}

Most of the current HIF experiments use alumino-silicate sources to produce potassium-ion beams. We use the WARP computer code³ to reduce aberrations in these systems as shown in Fig.1. Bench-marking the simulations against measured data has resulted in refinements to the code and to the experimental diagnostics.

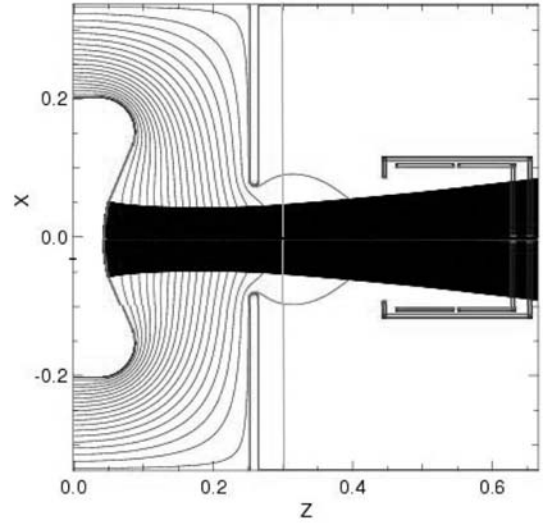


Fig. 1. Layout of experiments using a 10-cm source with 400-kV, 21-cm-wide gap. The figure shows the ion beam being transported into a faraday cup. We also will perform experiments into a pepper-pot mask and slit scanners to determine the beam’s characteristics.

II. BACKGROUND ON RF PLASMA SOURCE

Following a proposal that the usual limits on brightness for compact ion-beam sources used in Heavy Ion Fusion can be circumvented by using a multi-beamlet injector⁴ we have started an experimental program to examine practical issues. The final source envisioned will start with ~ 200 5-mA beamlets across a 100-kV gap. The beamlets will be focused by Einzel Lens while their energy is increased to about 1.0 MeV. The beamlets are then merged to produce a 1-A beam with a normalized 4^* rms emittance of 1π -mm-mrad at 1.6 MeV.

Beyond providing a low-temperature source that can provide ion emission densities of ~ 100 mA/cm², the main physics issues involved in the multi-beamlet approach are emittance growth and envelope matching in the merging process. In computer simulations, if the initial emittance is in the range of measured values, the final emittance

increases only weakly with the initial emittance of the individual beamlets.

In a preliminary design comparison, we found that a full-size injector system can be made up to 6 times smaller by using the new approach, as opposed to the traditional large aperture method. Likewise, we expect a similar reduction in cost.

III. STUDYING INDIVIDUAL BEAMLETS

We are using an rf plasma source to produce an argon ion beam. The plasma chamber has 26-cm inner diameter with multicusp permanent magnets to confine plasma (see Figure 2). RF power (~ 11 MHz) is applied to the source via a 2-turn, 11-cm diameter antenna inside the chamber for producing beam pulses of $20 \mu\text{s}$ at up to 10 Hz. We have shown that we can extract 100 mA/cm^2 from the chamber (see Fig. 3). Optimum performance has been with ~ 2 mTorr gas in the plasma chamber (see Fig. 4). At a tube plate voltage of 10 kV and a chamber pressure of 2 mTorr of argon gas, the power into the antenna was 22 kW. Experimentally, the tube plate voltage is recorded, and the rf power levels shown in the figures were determined assuming 2.2 kW/kV .

Our first step was to characterize the current in a single beamlet from the rf plasma source (see Fig. 3). We believe that the “roll-over” occurred when ions were lost during transport to the cup. As shown in Fig. 4 increasing the source pressure above 2 mTorr continued to increase the ion density in the chamber, but did not yield higher extracted currents from the gap. Increasing the source pressure will also increase the charge exchange in the gap.

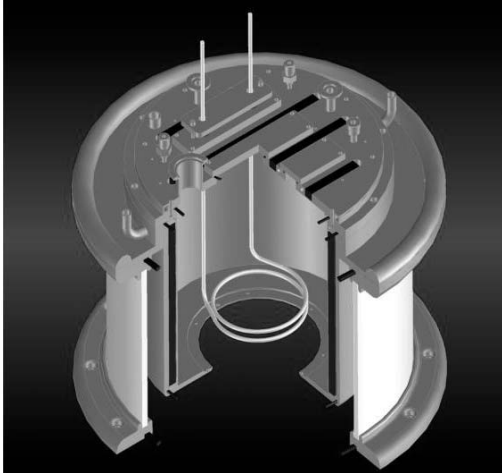


Fig. 2. RF plasma source used in the experiments.

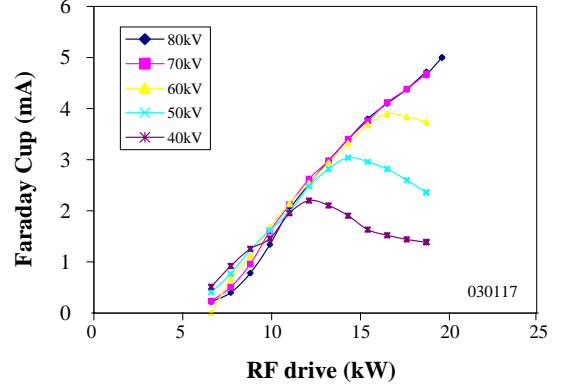


Fig. 3. Current detected at the Faraday Cup for a single beamlet at 2-mTorr source pressure. The source aperture was 2.5 mm diameter. The curves are at different gap potentials.

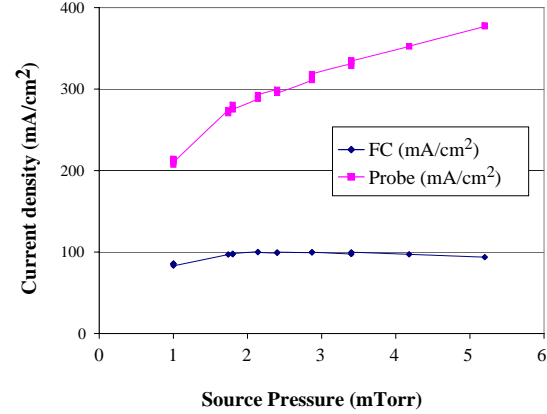


Fig.4. Effect of source pressure on extracted current and the ion density in the chamber. Gap voltage was 80 kV and the RF drive was 19 kW. The FC curve does not consider ions lost in transport.

A crude measurement of the ionization state was done by using time-of-flight information. We have a 1.5 meter drift section between pulsed dipole plates and a Faraday Cup. Since there was no focusing, the beam diameter at the cup was larger than its acceptance. We switched the beam into the Faraday Cup during the center of the pulse. The Ar^{++} ions will have higher momentum, and the front edge of the pulse will arrive at the Faraday Cup before the Ar^+ ions. At drive powers higher than 10 kW, we did see a “front step” in the ion current at the cup (see Fig. 5). We estimated that less than 5% of the extracted ions were in the Ar^{++} state.

We used a narrow slit and a slit cup to examine the $x - x'$ phase space of a beamlet. An example is shown in Fig. 6. The normalized emittance for the beamlet was about $0.02 \pi \cdot \text{mm} \cdot \text{mrad}$.

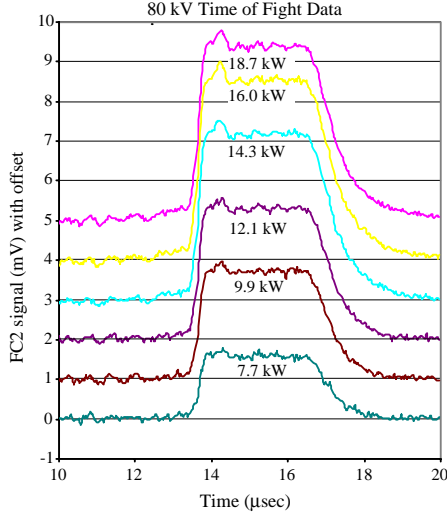


Fig. 5: Arrival time of ions at the back Faraday Cup.

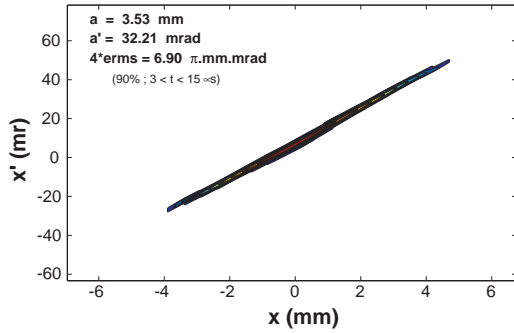


Figure 6: Phase space of a beamlet 12 cm from the extraction plate. Operation at 80kV, 2.1 mTorr source pressure, 18-kW RF drive. Cut taken at 90% of the peak value. Early values removed to reduce noise from the spark gaps. Unnormalized emittance shown.

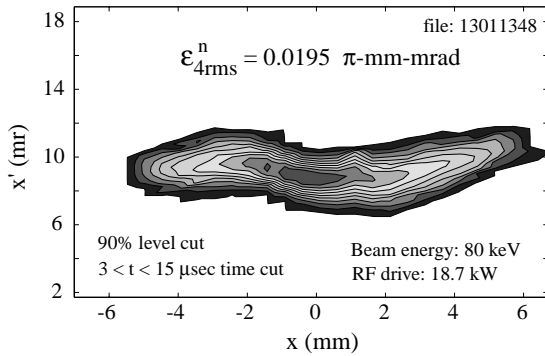


Fig. 7. Transformed phase space of the beamlet shown in the previous figure.

An early concern was that collisions between the extracted ions and the background gas would yield an excessive amount of charge exchange. The newly created ions would leave the gap with lower energies and

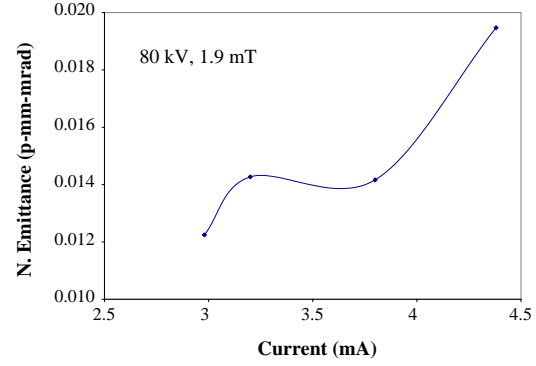


Fig. 8. Emittance vs. RF power

different transverse motion. Preliminary data showed that the energy spread of a beamlet is less than 1%, so the charge exchange problem is not significant after all.

IV. MULTI-BEAMLET EXPERIMENTS

We are presently testing a multi-beamlet extraction array. The bottom beam-forming plate in Fig. 9 has Pierce Cones for each of the beamlets. The apertures in the bottom plate are 2.2 mm diameter. The holes in the top plate are 4.0 mm diameter.

The plates shown in Fig. 9 are held with three High-Gradient Insulators. Above 60 kV across the 1.6 cm gap they will occasionally flash over, but usually recondition rapidly. They will hold 80-kV DC potential. A conservative working voltage would be about 40 kV/cm for a 20-μsec pulse in the gap environment.

Figure 10 shows the change in the opacity of a kapton sheet hit with 50-kV 20-μs beamlets from the array. The kapton sheet was 2 cm from the extraction plate. Figure 11 shows the profile of the center beamlet when the neighboring beamlets are blocked. Best emittance (optics) was obtained for operation around 12 kW drive for a gap potential of 50kV.



Fig. 9. Extraction plate for the 61-beamlet array.

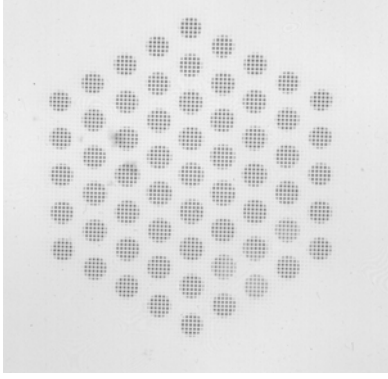


Fig. 10. Image of 61 beamlets on a Kapton sheet. The fine lines on the beam spots are due the presence of a mesh in front of the Kapton to neutralize the deposited beam charge.

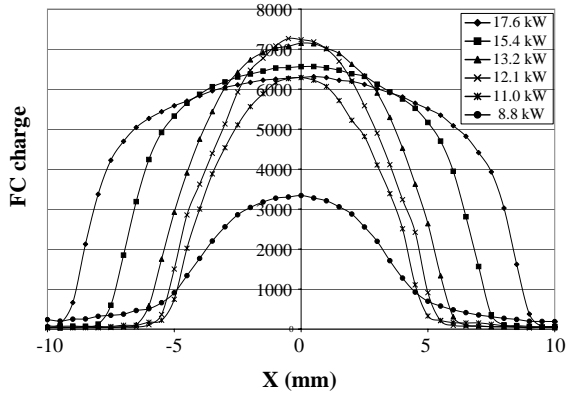


Fig. 11. Profile of the center 50-KeV beamlet for various RF drive levels. Measured 11 cm from the extraction plate with neighboring holes blocked.

VI. NEXT STEPS FOR THE RF PLASMA SOURCE

Our next step will be to add Einzel Lens to the present configuration (shown in Fig. 12). In latter versions the lens will also be used to boost the energy of the beamlets. We plan to separate the lens with high-gradient insulators. The separation of the lens is about 1 cm.

We will be testing a 80-kV 61-hole multi-beamlet array that should produce a total current greater than 200 mA. Merging of the beamlets will not be done at this stage because the perveance is too high. Also, minimizing the final transverse phase space will require curved plates for the Einzel Lens. We are designing an experiment with the extraction gap at about 100 kV with post acceleration up to 500 keV. The layout will be a scaled version of an injector for a single driver beam as shown in Fig. 13.

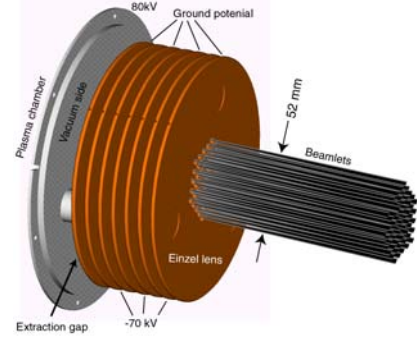


Fig. 12. Next experiment with extraction gap and Einzel Lens.

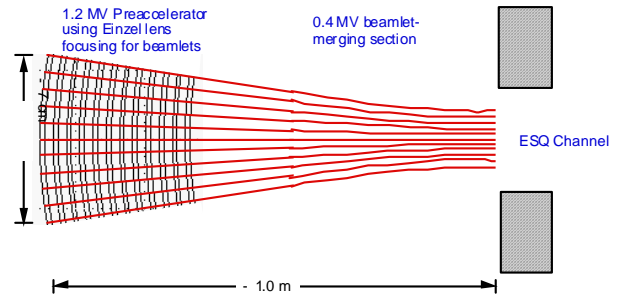


Fig. 13. Layout for the full injector using merging.

VII. ACKNOWLEDGEMENT

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VIII. REFERENCES

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